

Soil Physical Aspects of Integrated Crop-Livestock Systems

Alan J. Franzluebbers

Ecologist



Watkinsville GA

Soil Resources



Andisol



Mollisol



Spodosol

From the Soil Science Society of America Marbut Memorial Slide Set

Soil Functions

Soil: The Foundation of Life

Soil is a living entity that requires great care. It is a fragile, complex mix of minerals and microorganisms that can vary from one location to the next.

Food production depends on a complex web in the soil that includes fungi, bacteria and insect life. If we allow soil to degrade, its living systems will eventually break down and fail. When this happens, lifeless ground may blow away in the wind or wash away in the rain, taking with it our future.

Sustainable agriculture has its roots in the soil.



Providing for Life



<http://soilcrop.tamucorner.s.jpg>

Protecting and Interacting with the Environment

Atmosphere



Hydrosphere



Soil



Biosphere



Lithosphere



Key Physical Soil Functions

- ✓ Partitioning water (high water infiltration, adequate water retention in soil, and low volume of runoff)
- ✓ Providing a suitable rooting environment (unrestricted root development, no compaction, access to nutrients, no toxicity)
- ✓ Providing favorable habitat for microorganisms and animals (good aggregation, accessible energy sources, adequate water)



Integrated Crop-Livestock Systems

Some advantages

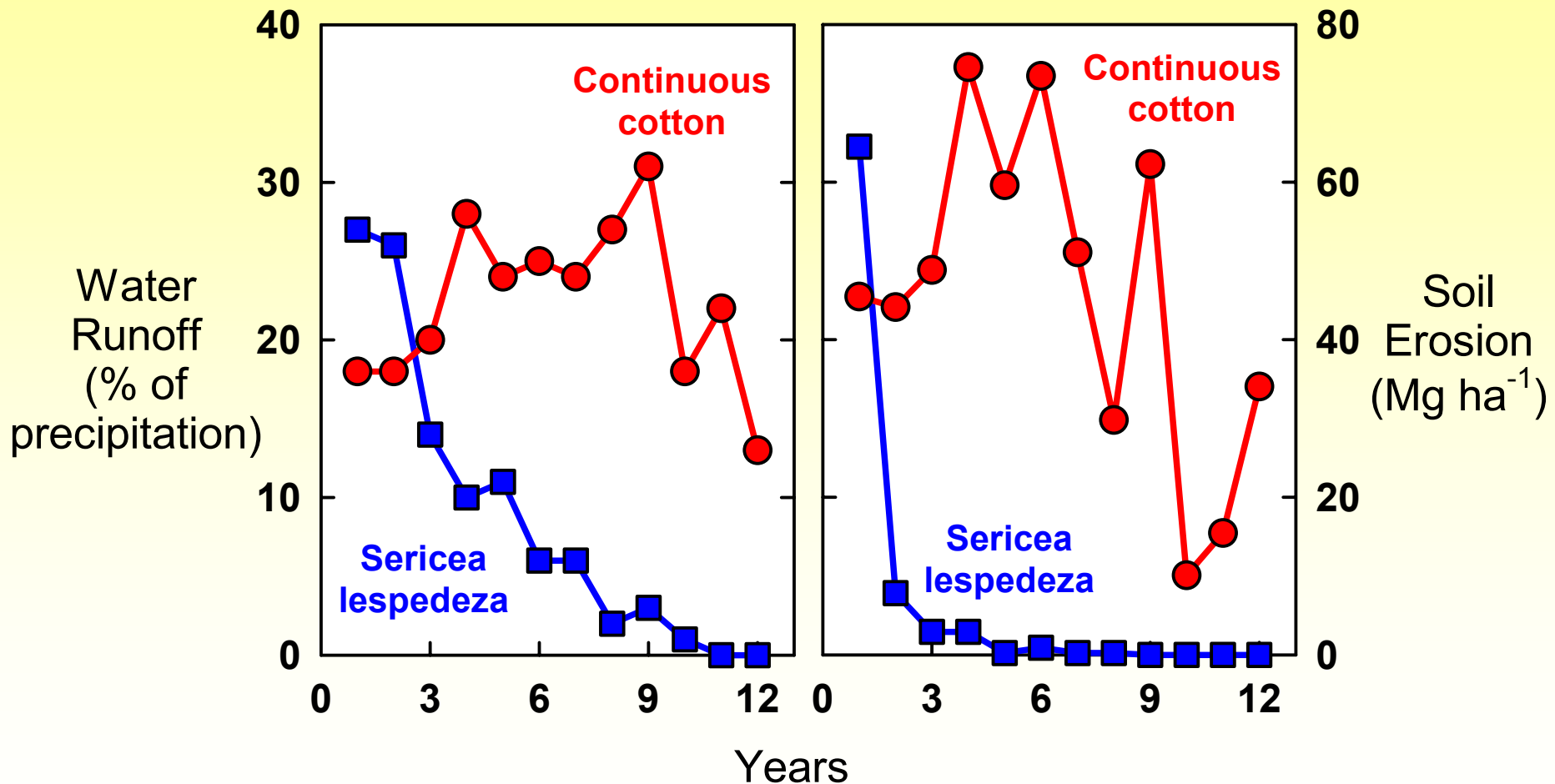
- ✓ Efficient utilization of natural resources
- ✓ Exploitation of natural pest control processes
- ✓ Reduction in nutrient loss and environmental risk
- ✓ Improvement in soil structure and productivity

Focus of this presentation

- ✓ How integrated crop-livestock systems might affect soil physical aspects



Soil Disturbance Effect on Water Runoff and Soil Erosion

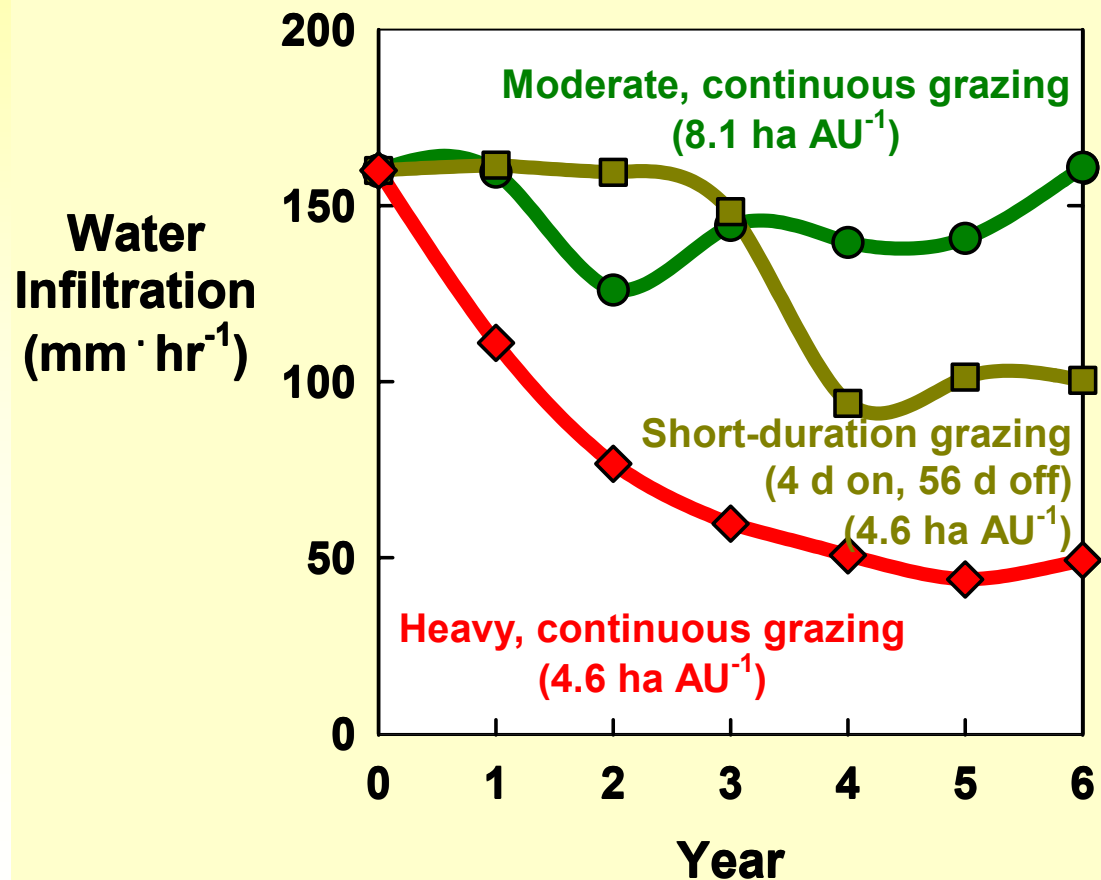


Grassland Management Effect on Water Infiltration

Achieving a balance between agricultural harvest and environmental protection is needed (i.e., stocking density should be optimized)

On an oak-grassland in central Texas (18 °C, 440 mm), water infiltration was highly related to percent ground cover

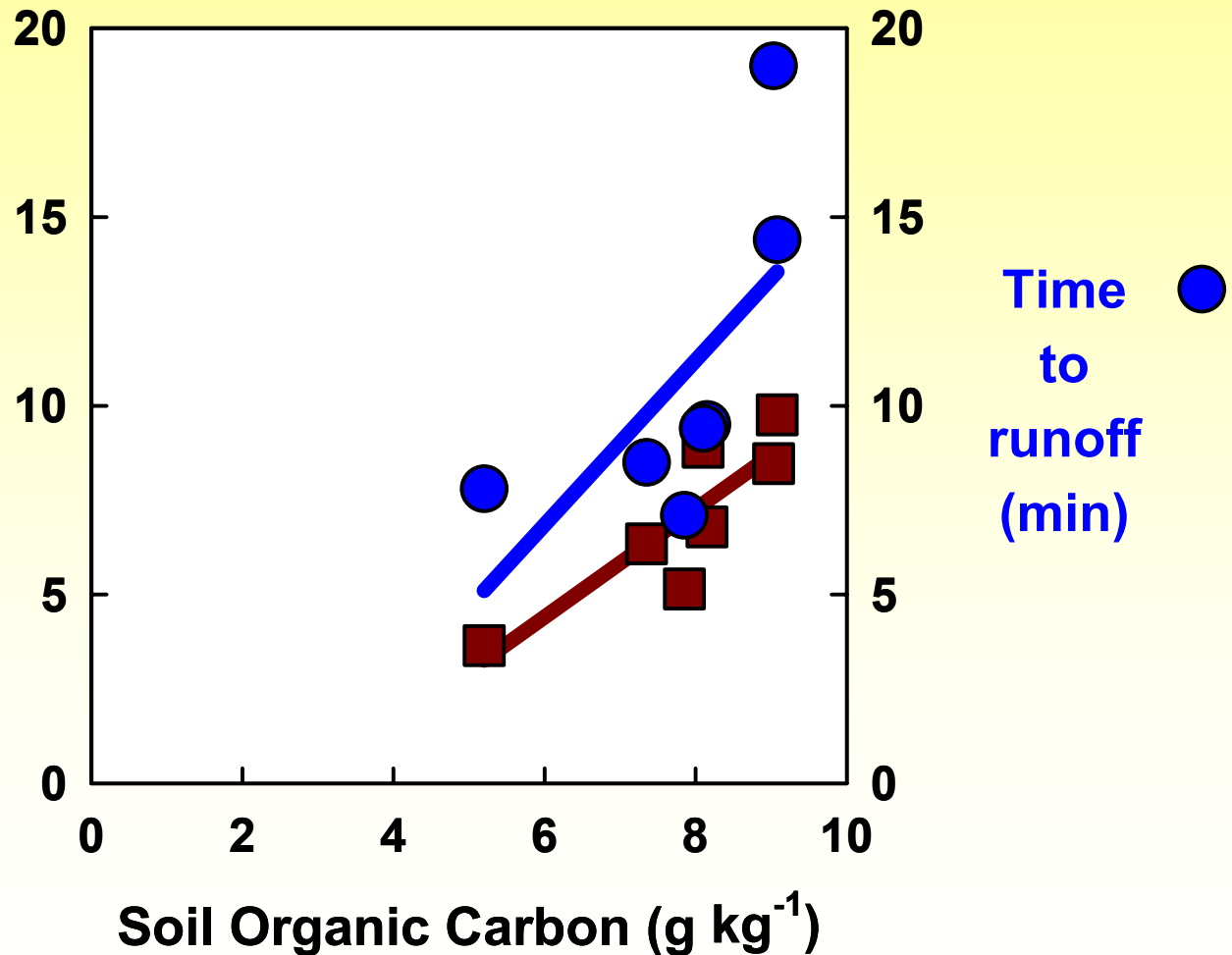
Management played a significant role



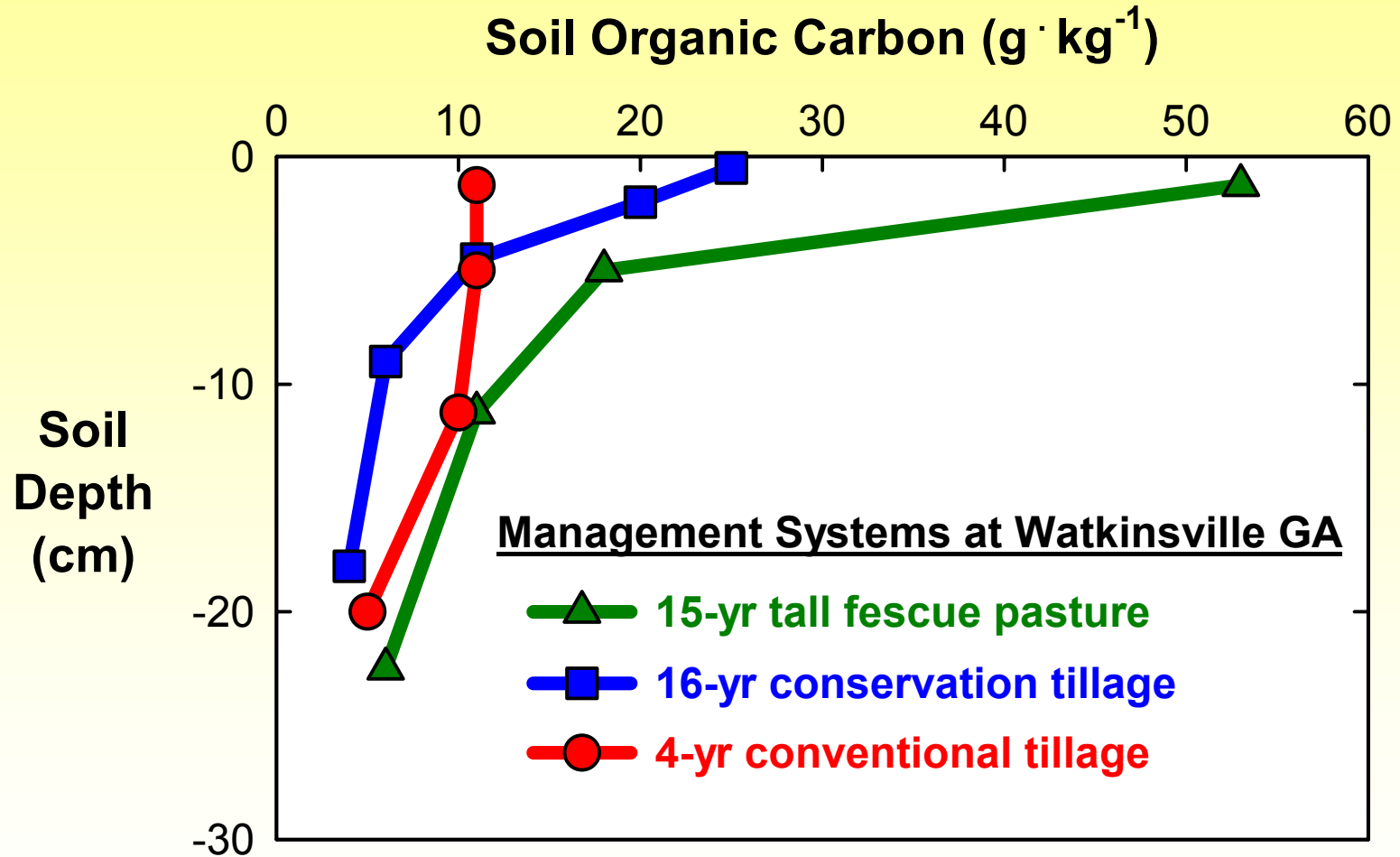
Relationship of Water Infiltration and Runoff to Soil Organic Matter



■ Infiltration
(cm hr⁻¹)

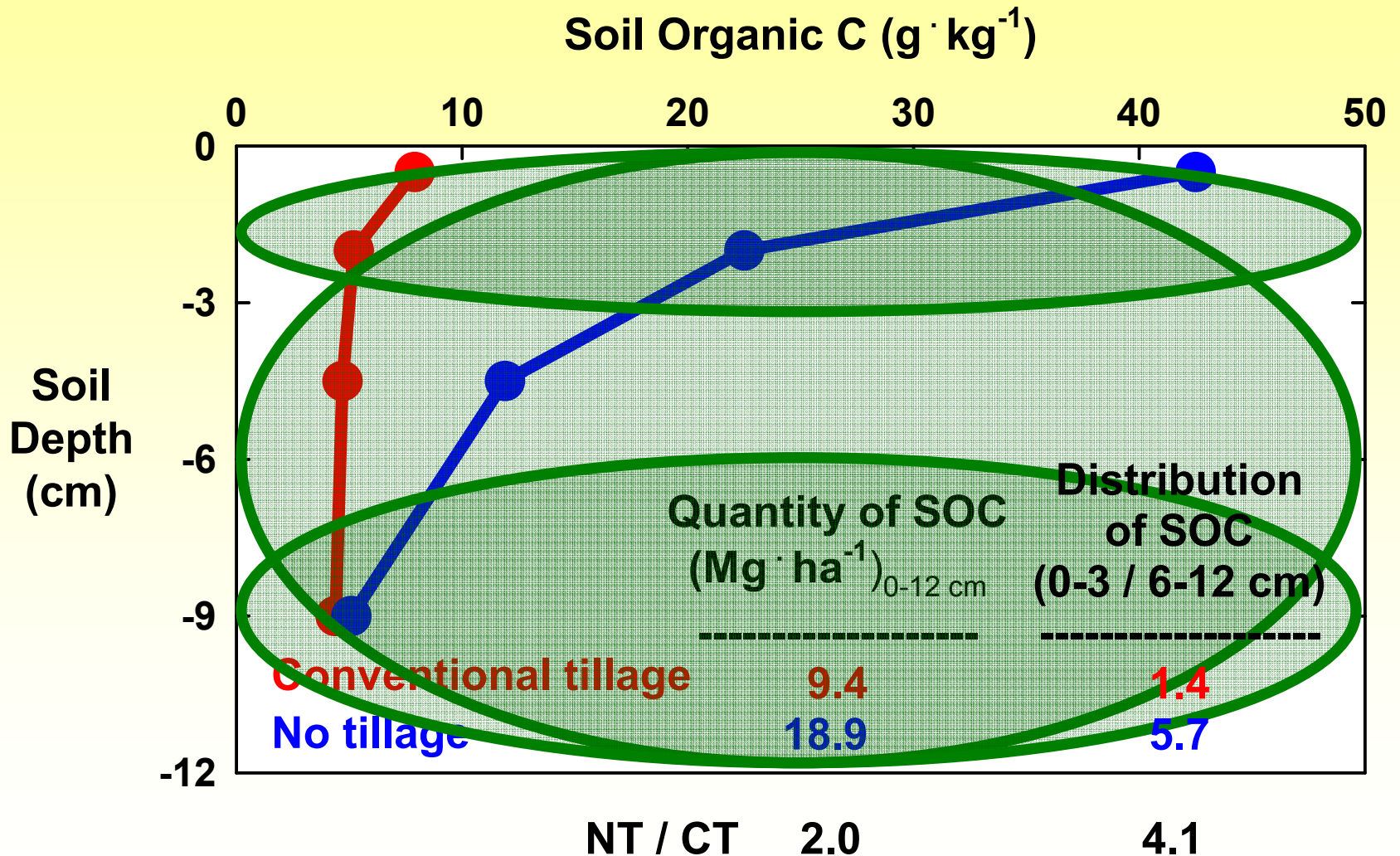


Accumulation of Soil Organic Matter



In the warm-humid region of the southeastern USA, organic matter accumulates near the soil surface when undisturbed.

Quantity *versus* Distribution of Soil Organic Matter



Effect of Soil Organic Matter on Water Infiltration



| | Infiltration Rate (mm min ⁻¹) | | |
|------------------------|--|----|------------|
| | ----- | | |
| <u>2x quantity</u> | CT | | NT |
| Sieved | 2.7 | < | 3.8 |
| <u>4x distribution</u> | | | |
| Intact | 2.2 | << | 8.2 |

Greater rate of infiltration due to stratified distribution of organic C, rather than quantity of organic C

The Problem with an Unprotected Soil Surface



Water Runoff from Small Plots

| Wisconsin Tillage | 1.4 m ² plots Runoff | Soil Loss | Phosphorus Loss | |
|-------------------------|------------------------------------|---------------------|---|----------------|
| | | | Total | Bioavailable |
| | % applied | Mg ha ⁻¹ | kg ha ⁻¹ event ⁻¹ | |
| CT: Conventional | 45 | 4.2 | 1.3 | 0.2 |
| NT: No Tillage | 22 | 0.3 | 0.2 | <0.1 |

Surface organic C was **33 Mg ha⁻¹ under CT (Conventional Tillage)** and **38 Mg ha⁻¹ under NT (No Tillage)**.

Surface soil P was **39 mg kg⁻¹ under CT** and **62 mg kg⁻¹ under NT**.

Despite higher soil P under NT than under CT, runoff P loss was lower due to greater water infiltration and less soil loss.

Water Runoff from Large Plots

| Virginia, 112 m ² plots | | | Runoff Nutrients | |
|------------------------------------|-----------|---------------------|---------------------|------------|
| Tillage | Runoff | Soil Loss | Nitrogen | Phosphorus |
| | % applied | Mg ha ⁻¹ | kg ha ⁻¹ | |
| CT: Conventional | 53 | 3.6 | 10.3 | 4.1 |
| NT: No Tillage | 12 | <0.1 | 0.5 | 0.3 |

Surface organic C was not reported, but expected to be greater under **NT (No Tillage)** than under **CT (Conventional Tillage)** due to long-term management.

If so, then distribution of organic C was important in preventing soil erosion and water quality deterioration.

Runoff from Water Catchments

| Oklahoma, 1.6-ha catchments, 5 years | | | Phosphorus Loss | | |
|--------------------------------------|------------|---------------------|--|-------------|---------|
| Tillage | Runoff | Soil Loss | Total | Particulate | Soluble |
| | % rainfall | Mg ha ⁻¹ | ----- kg ha ⁻¹ yr ⁻¹ ----- | | |
| CT: Conventional | 19 | 7.2 | 4.2 | 3.8 | 0.4 |
| NT: No Tillage | 24 | 0.4 | 1.7 | 0.5 | 1.2 |
| Native | 18 | <0.1 | 0.3 | 0.1 | 0.2 |

Surface organic C was not reported, but expected to be greater under **NT (No Tillage) (and native grass)** than under **CT (Conventional Tillage)** due to long-term management.

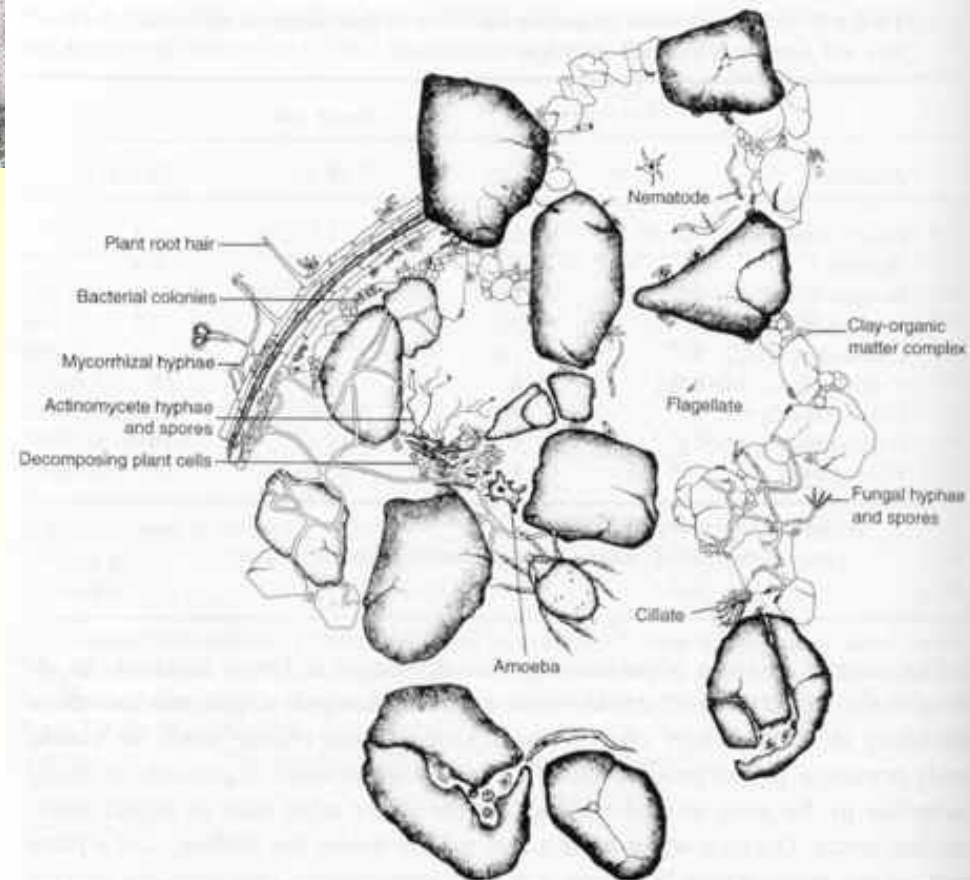
Similar to other studies, distribution of organic C likely contributed to prevention of environmental degradation, but possibility for greater soluble P loss is of concern.

Summary of the Role of Soil Organic Matter in Controlling Water Infiltration and Runoff

- ✓ Quantity of organic matter in “plow layer” is important
- ✓ Distribution of organic matter within soil profile may be more important, because of the importance of the soil surface in controlling initial water transport process
- ✓ Amount of sediment loss and water runoff is important consideration for nutrient loss and water quality implications
- ✓ Surface soil is also important in controlling the impact of traffic on other soil physical properties

Soil Aggregation

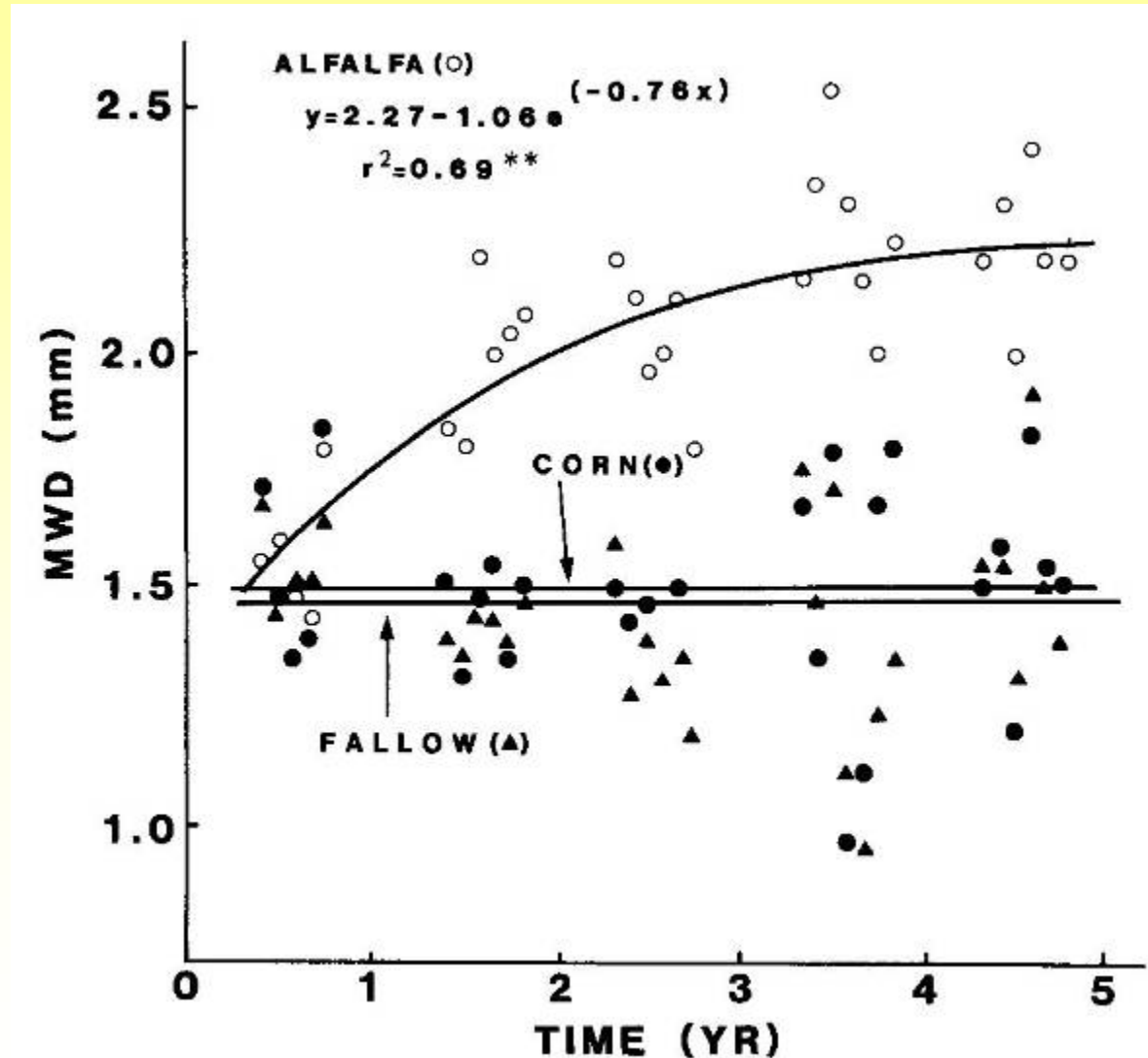
- ✓ Stabilizes soil surface against the energy input of rainfall and traffic (equipment and animals)
- ✓ Creates sufficient porosity for retention and transport of water and air
- ✓ Protects soil organisms from predation and rapid decomposition of organic matter



Soil Aggregation

✓ Mean-weight diameter of soil increased with establishment of a forage legume (alfalfa) that left soil undisturbed and enriched in soil organic matter.

✓ A relatively short time period (3-4 yr) was required to enrich the soil.



Soil Aggregation

✓ On silt loam and silty clay loam soils (Mollisols) in Iowa, soil aggregate stability was unaffected by monthly rotational grazing of cow-calf pairs on corn stalks in the winter [Clark et al. (2004) Agron. J. 96:1364-1371].

✓ At the end of 3 years on a sandy clay loam soil (Ultisol) in Georgia, stability of aggregation was similar whether cover crops (winter and summer cover crops) were grazed by cow-calf pairs for 1 ½ months each year (Franzluebbers and Stuedemann, unpublished data).



Summary of Soil Aggregation

- ✓ Grazing cattle under moderate stocking conditions will have little impact on stability of soil aggregation.
- ✓ Presence of grass roots and surface residue appears to be more important for aggregation than the presence of grazing animals.
- ✓ A recent literature review on stocking rate effects on aggregate size and stability [Greenwood and McKenzie (2001) Aust. J. Exp. Agric. 41:1231-1250] suggests a generally negative response to animal grazing...

But most responses were weak or related to intense treading.



Compaction

Soil compaction reduces porosity, thereby limiting air and water storage and transport...

which alters nutrient cycling and exploration potential of plant roots.

Compaction responses are often determined with:

- 1. Bulk density**
- 2. Penetration resistance**



Compaction from Animal Trampling

✓ Poaching of soil with heavy animal traffic can damage forage and cause soil compaction leading to reduced infiltration, greater water runoff, and contamination of receiving water bodies with nutrients and fecal-borne pathogens.

✓ In a review of grazing effects on bulk density [Greenwood and McKenzie (2001) *Aust. J. Exp. Agric.* 41:1231-1250], an increase in bulk density was observed with animal treading in most studies:

$$0.12 \pm 0.12 \text{ Mg m}^{-3} (n = 46)$$



✓ This situation represents an extreme treading condition, not what would be envisioned for an integrated crop-livestock system.

Bulk Density with Short-Term Grazing

✓ On silt loam and silty clay loam soils (Mollisols) in Iowa, soil bulk density was not affected by monthly rotational grazing of corn stalks during the winter, irrespective of whether soil was frozen or not [Clark et al. (2004) *Agron. J.* 96:1364-1371].

✓ On Mollisols in Argentina, soil bulk density increased with winter grazing of corn and soybean residues, but it depended on tillage system:

| | Ungrazed | | Grazed |
|----|--------------------|---|--------|
| | Mg m^{-3} | | |
| CT | 1.17 | < | 1.34 |
| NT | 1.25 | | 1.27 |

Diaz-Zorita et al. (2002) *Soil Till. Res.* 65:1-18



Stocker Grazing of Winter Cover Crop

| Soil property | Ungrazed | | Grazed |
|---|----------|---|--------|
| <hr/> | | | |
| Bulk density (Mg m^{-3}) | | | |
| Under conventional tillage | 1.71 | | 1.71 |
| Under conservation tillage | 1.72 | | 1.75 |
| Hydraulic conductivity (cm h^{-1}) | | | |
| Under conventional tillage | 4.4 | > | 3.4 |
| Under conservation tillage | 2.4 | < | 3.0 |
| <hr/> | | | |

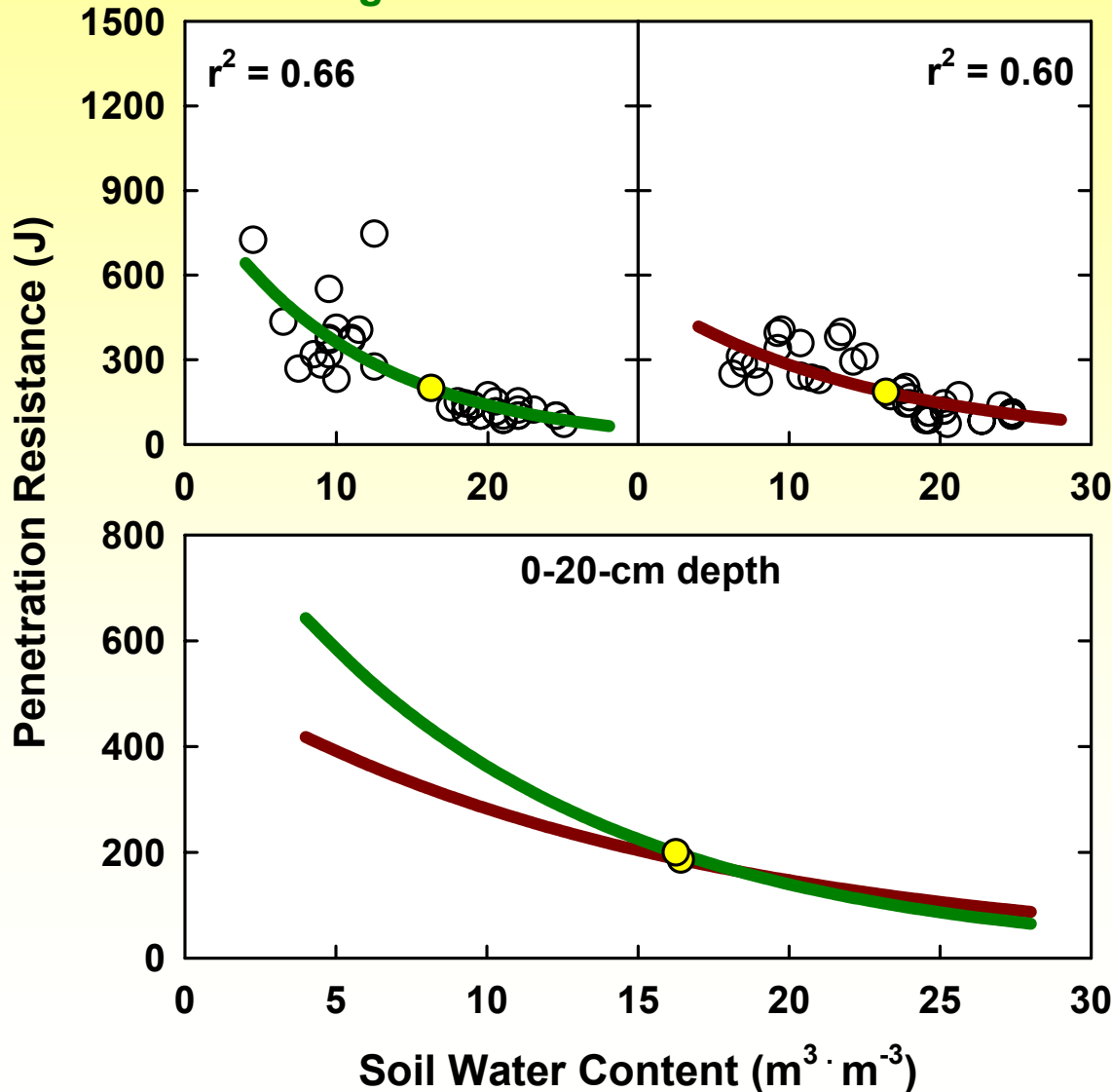


From Hill et al. (2004) UGA/CPES Res./Ext. Pub. No. 6, p. 40-45.

Cattle Grazing of Cover Crops

Ungrazed

Grazed



Soil penetration resistance (hardness) was highly related to soil water content.

Whether cattle grazed cover crops or not, had little impact on soil resistance, except at low soil water content.

Implications of Integrated Crop-Livestock Systems on Soil Physical Properties

- ✓ **The rooting environment** under integrated crop-livestock systems can be both negatively and positively impacted by animals introduced to cropping systems.
 - With high soil moisture and high stocking rate, animal trampling can compact soil and disrupt the soil surface to cause a reduction in plant growth and increased water runoff.
 - Long-term cropping systems in rotation with perennial grass can have high surface soil organic matter, robust soil structure, and continuous biopores due to undisturbed soil and high biological activity.
 - Managing crops with conservation tillage following pasture phases will likely preserve these positive grass-phase benefits and lead to enhanced production and environmental outcomes.

Implications of Integrated Crop-Livestock Systems on Soil Physical Properties

- ✓ **Water availability** under integrated crop-livestock systems may also be both negatively and positively impacted by animals introduced to cropping systems.
 - With an increase in soil organic matter, soil water retention, water infiltration, and water availability for crops will increase.
 - Intense animal traffic can poach vegetation and subsequently reduce water infiltration and availability.
 - Most literature on animal traffic effects has focused on extreme stocking densities that often lead to long-term damaged conditions.
 - However, well-managed, integrated crop-livestock systems should create opportunities to avoid continuous stocking of animals on perennial pasture, thereby distributing the stress of animal traffic onto a greater land area and across different times of the year.

Implications of Integrated Crop-Livestock Systems on Soil Physical Properties

- ✓ **Nutrient availability** under integrated crop-livestock systems will be altered compared with conventional cropping systems due to the processing of crop biomass through animals.
 - Direct physical impacts of grazing animals could reduce nutrient availability if losses of nutrients were exacerbated, such as through increased volatilization of ammonia, denitrification, and runoff losses of N, P, and other nutrients.
 - However, with enhanced soil organic matter and improvement in water infiltration and nutrient retention near the soil surface, nutrient availability could increase with integrated crop-livestock systems.
 - More research is needed to understand more of the implications of various integrated crop-livestock systems on the soil physical environment.